# MODELING OF NONLINEARITIES IN ACTUATORS FOR ROBOTICS

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## ABSTRACT

There is an effort to use unconventional actuators robotics more often now. Epitomes of these actuators are alloys with shape memory (SMA-Shape Memory Alloy). The efficient control of actuators based on shape memory principle is immediately related to results given by modeling in combination with practical experiments. The properties of SMA classified these actuators to category of non-linear system. This article deals with potential approaches to modeling of SMA. There are introduced examples of designed models and control. The article also presents the results of practical measurement performed in Department of Control and Measurement at Brno University of Technology and a description of robot actuated by SMA. Design of SMA actuator and comparison with classical actuator is discussed in the last part of this article.

## 1 INTRODUCTION

The metallic materials, which are able to generate memory effect, are known since first half of twentieth century. In 1932 the Swedish physicist named Arne Olander discovered the phenomenon of memory effect during the work with compound of cadmium (Cd) and gold (Au). It has seems as a miracle, but it was only result of internal crystallography changing.

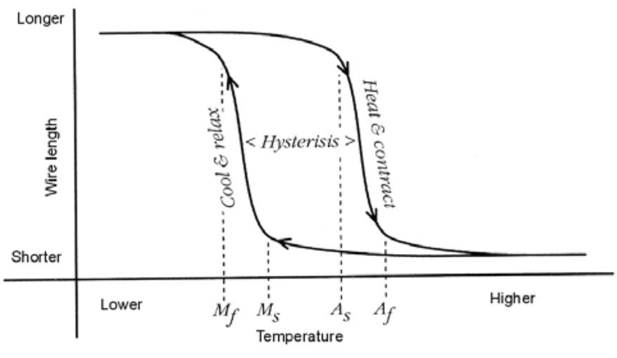


**Fig. 1:** *SMA length vs. temperature.*

## 2 MODELING OF SMA'S BEHAVIOUR

Modeling of behaviour of SMA wire is very complicated problem mainly because of complicated changes of crystalline structure of the material. Nevertheless there exist several types of models that are used not for control scheme design but for testing of already designed control scheme [4], [7], [9]. As the hysteresis is the main problem that is to be overcome by control, we use for modeling modification of model described in [5]. The force F developed by the wire is given the following equation.

$$F = D(X)\varepsilon S \tag{1}$$

D(X) is stress depending on X which is a fraction of martensite in crystalline structure of the wire.

$$D(X) = D_A + X(D_M - D_A) \tag{2}$$

$D_A$ and $D_M$ are stress constant for austenite and martensite respectively. X depends on temperature as was demonstrated on figure 1. For increasing temperature the following relation is valid.

$$X = X_0 \qquad \text{for } T \leq As$$

$$X = 0.5X_0\left[\cos K_M (T - A_s) + 1\right] \qquad \text{for } As < T < Af \tag{3}$$

$$X = 0 \qquad \text{for } T \geq Af$$

For decreasing temperature we use another relation.

$$X = X_0 \qquad \text{for } T \leq Mf$$

$$X = 0.5X_0\left[\cos K_M (T - M_f) + 1\right] \qquad \text{for } Ms > T > Mf \tag{4}$$

$$X = 0 \qquad \text{for } Ms < T$$

Where $X_0$ is starting fraction of martensite, T represents temperature and K is constant representing slope of curves in figure 1. In our experiments the wire is heated by electric current and we suppose that temperature of the wire is proportional to power of the current. Many of the constants of the model must be calculated from experiments or wire data sheet.

The other way, how to simulate this problem, is use another type of approximation function. From example use the tangent function, or completely another approach. We can find a general way how to solve the hysteresis problem in literature. One of them is the Preisach's model. This model should be a universal method, how to simulate the conventional nonlinearity type hysteresis. For the building of it, you must have required informations about concrete curve. These data is possible to take from a practise experiments realized on concrete SMA element.

## 3 EXPERIMENTS

In our departement we have made a few measurements with SMA. The result of one of them is on the picture 2. We worked with NiTi wire with diameter 0,152 mm. There is shown dependence between electric resistance and temperature. You can see there a typical hysteresis which is arise in SMA. This measure was realized in thermostat. In the case of this type of measure is necessary to reckon with a relative long time need for it. The data for this curve was gleaning two days.

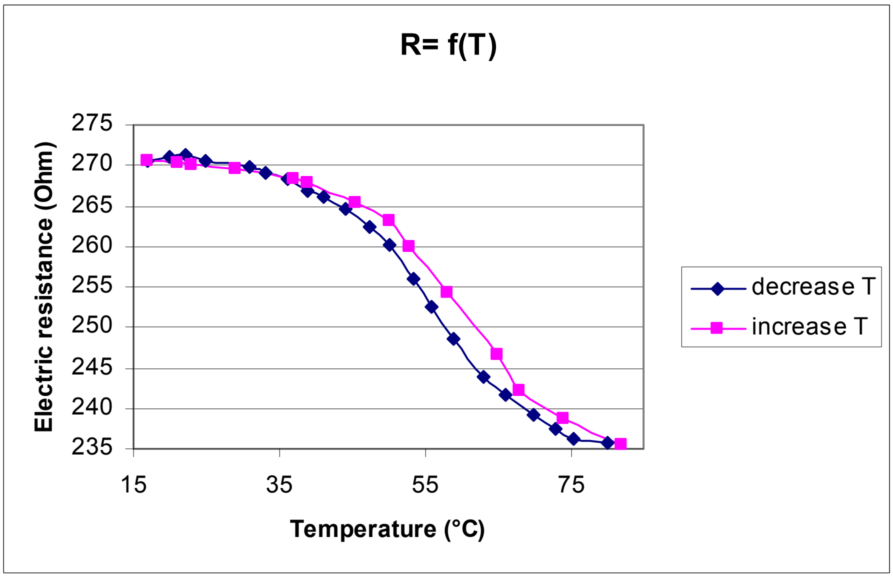


**Fig. 2:** *Electric resistance vs. temperature*

## 4 THE ISSUES

The implementation of this unconventional actuator to practise applications is restricted in addition to problems which were mentioned. We can find an advantages and also disadvantages considering to classical types of actuators.

| ***Advantages*** | ***Disadvantages*** |
|---|---|
| Silent run | External temperature heating |
| Very good ratio weight/generated force | Problematic connection |
| Availability | Modeling |
| Etc. | Etc. |

The Maximum Recovery Ratio (MRR) which represents percentage expressing the largest change in length is about 8 %. Most wires can perform only several cycles at this maximum deformation. Recommended Recovery Ratio (RRR) for maximum wire life is about 4 %. On the other site, thanks to internal pressures, the pole with diameter 4,2 mm made from NiTi compound is able to lift 1000 Kg.

## 5 CONCLUSION

SMA materials are nowadays used in medicine and industry as very simple and reliable expanders and fasteners. They are also used as direct passive controllers of temperature in building and automobile industry. Their application as actuators was until now limited only to on-off (fully stretched – fully contracted) control. Application of SMA in continuous position control is hindered by highly non-linear behaviour of the SMA material. This phenomenon makes research in SMA actuators a challenging task. Continually growing progress in control theory, computing power and sensor technology makes the problem solvable in near future. Extreme power to weight ratio, high reliability and no need of maintenance makes drives based on SMA very attractive. Results described in the article show that relatively good performance can be reached with very simple equipment

## ACKNOWLEDGEMENTS

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## REFERENCES

[1] Ikuta, K., Tsukamoto, M., Hirose, S.: Shape Memory Alloy Servo Actuator System With Electric Resistance Feedback and Application for Active Endoscope, Proc. of the 1988 IEEE International Conference on Robotics and Automation, Vol. 1.,Computer Society Press, Washington, DC.

[2] Bar-Cohen,Y.: Topics on Nondestructive Evaluation. Vol. 4. American Society for Nondestructive Testing. 2000. ISBN 1-57117-043-X

[3] Drahoš, P.: Model of Shape Memory Alloy Drive. In: Proceedings of 2nd Conference TASCOM 97 in SR (Žilina). Vol.3. University of Žilina 1997. pp.265-268

[4] Drahoš, P.: Thermodynamic Model of SMA Drive. In: Proceedings of 4nd Conference Process Control 2000 in CR (Kouty nad Desnou),University of Pardubice

[5] Conrad, J. M., Mills, J. W.: Stiquito, Advanced experiments with a simple and inexpensive robot, IEEE Computer Society Press, Los Alamitos, Calofornia, 1998, ISBN 0-8186-7408-3

[6] Grant, D.: Accurate and Rapid Control of Shape Memory Alloy Actuators, Doctoral thesis, Department of Electrical and Computer Engineering McGill University, 1999

[7] Otsuka, K., Wayman, C. M.: Shape Memory Materials, Cambridge University Press, 1998, ISBN 0 521 44487

[8] Hasegawa, T., Kodama, K., Majima, S.: Modeling of Shape Memory Alloy Actuator and Tracking Control System with the Model, IEEE Transactions of Control Systems Technology, Vol.9, NO.1, January 2001

[9] Tondu, B., Lopez, P.: Modeling and Control of McKibben Artificial Muscle Robot Actuators, IEEE Control Systems Magazine, pages 15 – 38, April 2000.